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Lund, Mia Schou Møller; Hansen, Kurt Kielsgaard

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Shrinkage Properties of Cement Stabilized Gravel



Mia S. M. Lund
MSc, PhD Student
DTU Civil Engineering
Brovej, Building 118
DK - 2800 Kgs. Lyngby
msml@byg.dtu.dk



Kurt Kielsgaard Hansen
Associate Professor, PhD
DTU Civil Engineering
Brovej, Building 118
DK - 2800 Kgs. Lyngby
kkh@byg.dtu.dk

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ABSTRACT

Cement stabilized gravel is an attractive material in road construction because its strength properties are accommodating the increasingly higher requirements to the bearing capacity of a base course. However, reflection cracking of cement stabilized gravel is a major concern. In this paper the shrinkage properties of cement stabilized gravel have been documented under various temperature and relative humidity conditions. Two cement contents corresponding to a 28-days compressive strength of 6.2 MPa and 12.3 MPa have been tested and compared. It is found that the coefficient of linear expansion for the two cement contents is $9.9 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$ and $11.3 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$, respectively. Furthermore, it is found that reflecting cracking can mainly be explained by temperature dependent shrinkage rather than moisture dependent shrinkage.

1. INTRODUCTION

Semi-rigid pavements used for highways gained increasing popularity in Denmark during the 1970's. A semi-rigid pavement consists of a base course of cement stabilized gravel and an asphalt concrete layer. Some of the main advantages by using cement stabilized gravel compared to unbound gravel are improved bearing capacity and durability. However, during the 1980's the use of cement stabilized gravel was stopped due to the pavements from the 1970's beginning to show signs of reflection cracking. In recent years different methods have been developed attempting to prevent reflection cracking. The most common method is crack control where cracks are cut halfway through the layer of cement stabilized gravel at every 2 m. However, there is still a great lack in understanding the underlying phenomena which cause reflection cracking. This paper investigates the temperature and moisture dependent shrinkage properties of cement stabilized gravel.

2. METHODS

2.1. Specimen preparation

One type of 0-16 mm gravel material from Nymølle pit, Denmark, has been investigated. A sieve analysis performed in accordance with DS/EN 933-1:2012 classified the gravel as belong-

ing to Envelope B with an oversize of 7% on the 16 mm sieve, cf. EN 14227-1:2004. Figure 1 (left) shows the grain curve for the gravel material.

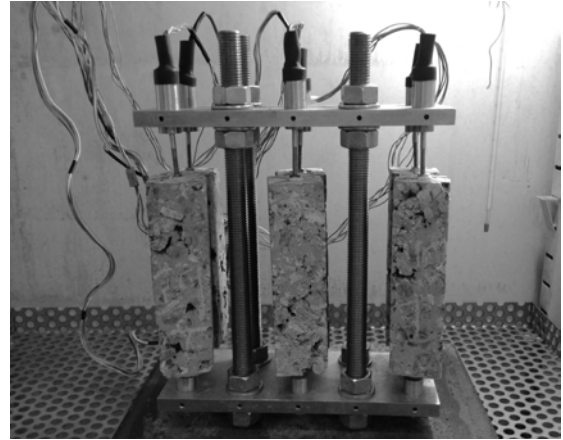
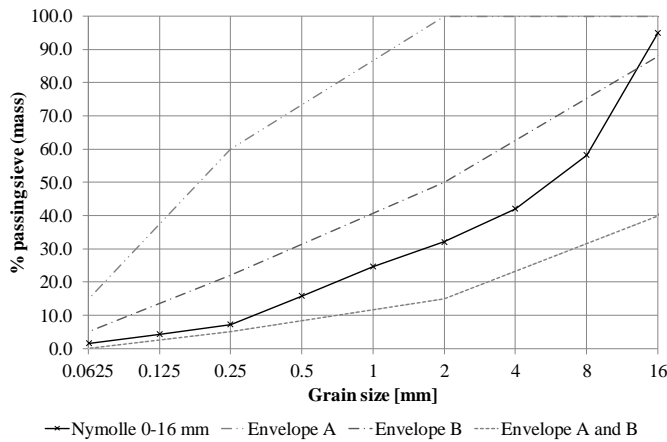


Figure 1 – Left: Grain size distribution of gravel (Nymølle 0-16 mm) with envelopes according to DS/EN 14227-1:2004. Right: Shrinkage setup in climate chamber. Six cement stabilized gravel specimens with dimensions of 4 cm x 4 cm x 15 cm were tested. Three of the specimens had a cement content of 4% and three had a cement content of 5%.

Two different cement contents of 4% and 5% of the dry material were chosen. The optimal water content was determined from proctor tests in accordance with DS/EN 13286-2:2012 by also including the influence of cement. The mixture was prepared by mixing gravel, low alkali cement and water in the right proportions for three minutes. The specimens were cast in accordance with EN 13286-50:2004 using the vibrating table compaction method. Split moulds with a diameter of 150 mm and a height of 300 mm were used. The minimum degree of compaction, which is defined as the ratio between the actual density of the specimen and the optimal density determined from proctor tests, was 97.4%. After 28-days of curing in a 20°C water basin a number of the cylinder specimens were cut into prisms with dimensions of 4 cm x 4 cm x 15 cm.

2.2. Experimental procedure

The compressive strength was measured on D150mm/H300mm cylinders on a TONI 3000 kN machine at a velocity of 3 and 5 kN/s for 4% and 5% cement content, respectively. Six cylinders of each cement content were tested after 28-days of curing in a 20°C water basin.

The shrinkage test was carried out in a SKANFRYS climate chamber with a temperature range of -10°C to +60°C and a relative humidity range of 10% to 95%. Extensometers with an accuracy of 2 µm and a measuring range of ±5 mm were used. Three specimens of each cement content were tested. The setup in the SKANFRYS climate chamber can be seen in Figure 1 (right). The specimens were mounted in vertical position in a steel frame.

Four different tests were carried out. In the first test the relative humidity was fixed at 65% and the temperature was varied between 5°C and 20°C. In the second test the relative humidity was fixed at 65% and the temperature was varied between 5°C and 40°C. In the third test the temperature was fixed at 20°C and the relative humidity was varied between 65% and 85%. In the fourth test the temperature was fixed at 20°C and the relative humidity was varied between 45%

and 85%. In all four tests the conditions were first changed when a steady deformation was obtained. Furthermore, two repetitions were made in all tests to underpin the observations.

3. RESULTS

The 28-days compressive strength of the cylinder specimens are shown in Table 1.

Table 1 – 28-days compressive strength, f_c , of specimens shown as average \pm standard deviation.

Cement content [%]	4	5
f_c [MPa]	6.2 ± 0.6	12.3 ± 2.3

The calculation of the strain induced by the variation in either temperature or relative humidity was found as the difference in strain between the measured steady strain at e.g. 5°C and 20°C. The strain calculations for a temperature variation were corrected with respect to the deformation of the steel frame. This was done by estimating the coefficient of linear expansion of the steel frame itself by inserting an Invar steel bar in the frame. The deformation measured over the Invar steel bar was assumed to correspond to the deformation of the steel frame since the Invar steel bar has a negligible coefficient of linear expansion.

For the variation in temperature the coefficient of linear expansion was calculated as:

$$\varepsilon = \alpha \cdot \Delta T \quad (1)$$

where ε is the strain, α [$^{\circ}\text{C}^{-1}$] is the coefficient of linear expansion and ΔT [$^{\circ}\text{C}$] is the temperature change. Figure 2 shows the strain variation and corresponding variation in temperature and relative humidity for test no. 1 and no. 3.

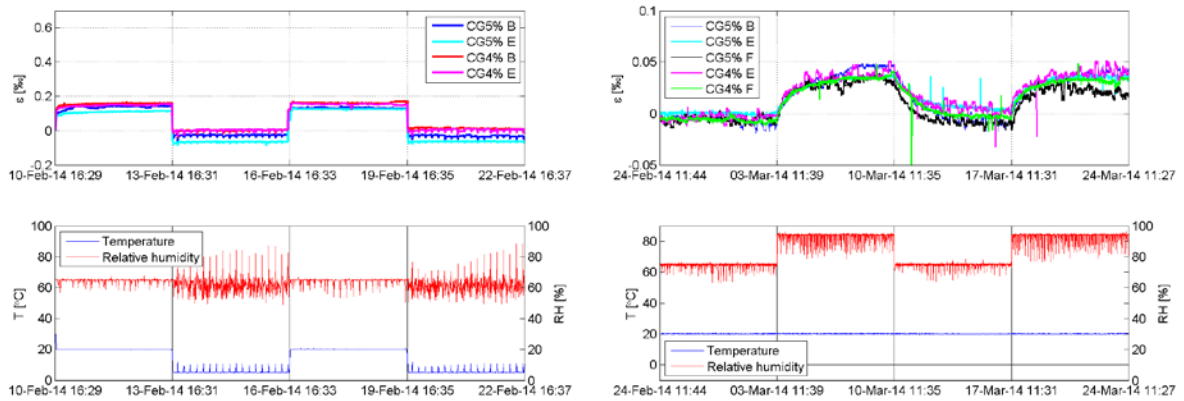


Figure 2 – Variation in strain, ε , for test no. 1: $RH = 65\%$ and $T = 5^{\circ}\text{C} - 20^{\circ}\text{C}$ (left) and for test no. 3: $T = 20^{\circ}\text{C}$ and $RH = 65\% - 85\%$ (right).

Table 2 shows the average results of strains and coefficients of linear expansion for each cement content. Obviously incorrect results have been omitted when calculating the average values.

Table 2 – Strains, ε , and coefficients of linear expansion, α , for various boundary conditions.

No.	RH	T	4 % cement		5 % cement	
1	65 %	5°C to 20°C	$\varepsilon = 1.5 \times 10^{-4}$	$\alpha = 9.9 \times 10^{-6} \text{ } ^{\circ}\text{C}^{-1}$	$\varepsilon = 1.7 \times 10^{-4}$	$\alpha = 11.2 \times 10^{-6} \text{ } ^{\circ}\text{C}^{-1}$
2	65 %	5°C to 40°C	$\varepsilon = 3.5 \times 10^{-4}$	$\alpha = 9.9 \times 10^{-6} \text{ } ^{\circ}\text{C}^{-1}$	$\varepsilon = 4.0 \times 10^{-4}$	$\alpha = 11.4 \times 10^{-6} \text{ } ^{\circ}\text{C}^{-1}$
			Average: $\alpha = 9.9 \times 10^{-6} \text{ } ^{\circ}\text{C}^{-1}$		Average: $\alpha = 11.3 \times 10^{-6} \text{ } ^{\circ}\text{C}^{-1}$	
3	65% to 85%	20°C	$\varepsilon = 3.6 \times 10^{-5}$	-	$\varepsilon = 3.5 \times 10^{-5}$	-
4	45% to 85%	20°C	$\varepsilon = 8.5 \times 10^{-5}$	-	$\varepsilon = 8.4 \times 10^{-5}$	-

4. DISCUSSION

Considering the tests where the relative humidity was kept constant and the temperature was varied it can be seen from Table 2 that the coefficient of linear expansion as expected is independent on the interval of the temperature variation. This is both observed for a cement content of 4% and 5% with an average coefficient of linear expansion of $9.9 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$ and $11.3 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$, respectively. A cement content of 4% and 5% corresponds to a 28-days compressive strength of 6.2 MPa and 12.3 MPa, respectively. An increment of 14% is observed when the cement content is increased from 4% to 5%. Considering the tests where the temperature was kept constant and the relative humidity was varied it can be seen that the size of the strains approximately doubles when the range of the relative humidity variation is doubled. This is both observed for a cement content of 4% and 5%. However, no unambiguous tendency is observed between the strains for a cement content of 4% and 5%. A slightly larger strain is observed for a cement content of 4% compared to 5% in both test no. 3 and no. 4. However, the small difference is rather explained by the uncertainty of the measurements than by an actual difference and the strains must be considered to be the same size of order.

The temperature and relative humidity intervals applied in the tests have been chosen in accordance with realistic values that pavements can be expected to be exposed to. Hence, it is of interest to compare the size of the strains induced by a variation in temperature and in relative humidity. From Table 2 it can be seen that the size of the strains induced by a variation in relative humidity is an order of magnitude less than the strains induced by a temperature variation. This means that the reflecting cracking observed in semi-rigid pavements is mainly expected to be due to the temperature dependent shrinkage properties of cement stabilized gravel.

5. CONCLUSION

The strain variation of cement stabilized gravel has been measured for two different cement contents under different temperature and relative humidity conditions. A coefficient of linear expansion of $9.9 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$ has been found for cement stabilized gravel with a cement content of 4% which is corresponding to a compressive strength of 6.2 MPa. A slightly higher coefficient of linear expansion of $11.3 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$ has been found for cement stabilized gravel with a cement content of 5% which is corresponding to a compressive strength of 12.3 MPa. Furthermore, the strains induced by a variation in relative humidity have been found to be an order of magnitude less than the strains induced by a variation in temperature. This indicates that the main cause of reflection cracking in semi-rigid pavements is temperature dependent shrinkage.

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